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Frontiers of Scientific Computing Lecture Series

Computational Geometry and Computational Mechanics

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Abstract:
Geometry is the foundation of analysis yet modern methods of computational geometry have until recently had very little impact on computational mechanics. The reason may be that the Finite Element Method (FEM), as we know it today, was developed in the 1950's and 1960's, before the advent and widespread use of Computer Aided Design (CAD) programs, which occurred in the 1970's and 1980's. Many difficulties encountered with FEM emanate from its approximate, polynomial based geometry, such as, for example, mesh generation, mesh refinement, sliding contact, flows about aerodynamic shapes, buckling of thin shells, etc. It would seem that it is time to look at more powerful descriptions of geometry to provide a new basis for computational mechanics. At least two themes have recently emerged with this spirit. One is based on the Isogeometric concept utilizing NURBS and the other is based on Subdivision Surfaces. Both approaches have been demonstrated to have considerable potential and several advantages over typical FEMs. The purpose of this talk is to explore the new generation of computational mechanics procedures based on modern developments in computational geometry. The emphasis will be on the Isogeometric approach in which basis functions generated from NURBS (Non-Uniform Rational B-Splines) are employed to construct an exact geometric model. For purposes of analysis, the basis is refined and/or its order elevated without changing the geometry or its parameterization. Analogues of finite element h- and p-refinement schemes are presented and a new, more efficient, higher-order concept, k-refinement, is described. Refinements are easily implemented and exact geometry is maintained at all levels without the necessity of subsequent communication with a CAD (Computer Aided Design) description. In the context of structural mechanics, it is established that the basis functions are complete with respect to affine transformations, meaning that all rigid body motions and constant strain states are exactly represented. Standard patch tests are likewise satisfied. Numerical examples exhibit optimal rates of convergence for linear elasticity problems and convergence to thin elastic shell solutions. Extraordinary accuracy is noted for structural vibrations calculations. A k-refinement strategy is shown to converge toward monotone solutions for advection-diffusion processes with sharp internal and boundary layers, a very surprising result. It is argued that Isogeometric Analysis is a viable alternative to standard, polynomial-based, finite element analysis and possesses many advantages.

Speaker's Bio:
Dr. Hughes holds B.E. and M.E. degrees in Mechanical Engineering from Pratt Institute and an M.S. in Mathematics and Ph.D. in Engineering Science from the University of California at Berkeley. He began his career as a mechanical design engineer at Grumman Aerospace, subsequently joining General Dynamics as a research and development engineer. Upon receiving his Ph.D. at Berkeley, he received the Bernard Friedman Prize in Applied Mathematics, and thereafter taught at Berkeley eventually moving to California Institute of Technology and then Stanford University before joining the University of Texas at Austin. At Stanford he served as Chairman of the Division of Applied Mechanics, Chairman of the Department of Mechanical Engineering, Chairman of the Division of Mechanics and Computation, and occupied the Mary and Gordon Crary Family Chair of Engineering. At the University of Texas at Austin, he is Professor of Aerospace Engineering and Engineering Mechanics and occupies the Computational and Applied Mathematics Chair III. He is a Fellow of the American Academy of Mechanics, the American Society of Mechanical Engineers (ASME), the American Institute of Aeronautics and Astronautics, the American Society of Civil Engineering (ASCE), and the American Association for the Advancement of Science, co-editor of the international journal Computer Methods in Applied Mechanics and Engineering, a Founder, Fellow and past President of the U.S. Association for Computational Mechanics (USACM), a Founder, Fellow and past President of the International Association for Computational Mechanics (IACM), a past Chairman of the Applied Mechanics Division of ASME, and is licensed to practice as a Professional Engineer in the state of Texas. Dr. Hughes has been a leading figure in the development of the field of computational mechanics. He has published over 300 works on computational methods in solid, structural and fluid mechanics and he is one of the most widely cited authors in the field. Dr. Hughes was identified by ISI as among the 15 most highly cited authors in Computer Science and the original 100 most highly cited authors in Engineering (all fields). His research has included many pioneering studies of basic theory as well as diverse applications to practical problems. He received the Walter L. Huber Civil Engineering Research Prize in 1978 from ASCE, the Melville Medal in 1979 from ASME, and the 1993 Computational Mechanics Award of the Japan Society of Mechanical Engineers. In 1995 Dr. Hughes was elected to membership in the National Academy of Engineering. In 1997 he was awarded the Von Neumann Medal, the highest award of USACM, and in 1998 he received the Gauss-Newton Medal, the highest award of IACM, and was named the recipient of the Worcester Reed Warner Medal from ASME. He was the first engineer to occupy the Cattedra Galileiana (Galileo Galilei Chair), Scuola Normale Superiore, Pisa, in 1999, and he held the Eshbach Professorship, Northwestern University, in 2000. In 2003, Dr. Hughes received a Doctorat honoris causa from the Universite catholique de Louvain, Belgium. His seminal studies on contact-impact, plate and shell elements, time integration procedures, incompressible media, algorithms for inelastic materials, nonlinear solution strategies, iterative equation solvers, parallel computing, and finite elements for fluids have had a major impact on the development of software used throughout the world today. His most recent work includes the determination of hydrodynamic noise sources in turbulent flows, simulation based medical planning for cardiovascular disease and predictive surgery, study and application of Large-Eddy Simulations (LES) in turbulence, multiscale methods in science and engineering, and Isogeometric Analysis: geometrically exact methods in computational mechanics.

This lecture has a reception.

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